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Technical Report 32-1415

*The 25-ft Space Simulator at the
Jet Propulsion Laboratory*

J. W. Harrell

M. J. Argoud

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CALIFORNIA INSTITUTE OF TECHNOLOGY
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Preface

The work described in this report was performed by the Environmental Sciences Division of the Jet Propulsion Laboratory.

This report supersedes previously published Technical Memorandum 33-319, *Preliminary Description of the Modified JPL 25-ft Space Simulator*, by M. J. Argoud, dated February 1, 1967.

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Abstract

A description is presented of the 25-ft space simulator at the Jet Propulsion Laboratory, which is designed for environmental testing of unmanned spacecraft under simulated interplanetary conditions of extreme cold, high vacuum, and intense solar radiation.

The 25-ft Space Simulator at the Jet Propulsion Laboratory

I. Introduction

The 25-ft space simulator at JPL is designed for environmental testing of unmanned spacecraft under simulated interplanetary conditions of extreme cold, high vacuum, and intense solar radiation. Typical tests include heat-balance and temperature-distribution studies, investigations of subsystem interactions, tests of attitude-control equipment and sensors, and acceptance tests of flight spacecraft. Figure 1 shows a cross section of the test facility. Figure 2 is a perspective view of the simulator.

II. Facility Description

The simulator chamber is a stainless-steel cylindrical vessel 27 ft in diameter and 85 ft high; a 16-ton, 15- by 25-ft side-opening access door is provided for test-item loading. A personnel door provides entry through the access door. The minimum operating pressure of the chamber is 10^{-6} torr. The walls and floor are lined with thermally opaque aluminum cryogenic shrouds controlled over a temperature range of -320 to $+250^{\circ}\text{F}$. An off-axis solar simulation system is provided by an array of 37 xenon 20-kW compact arc lamps. This array provides a simulated solar beam that is reflected down into the test

volume by a 23-ft collimating mirror, which is temperature-controlled with gaseous nitrogen through a range of -100 to $+200^{\circ}\text{F}$.

The test volume of the simulator, 20 ft in diameter by 25 ft high, is irradiated by a 15-ft-diam beam of simulated solar energy at intensities up to 236 W/ft^2 for test durations of 400 h. The maximum energy available with the 15-ft beam is 314 W/ft^2 . The spectrum is that of xenon compact arc lamps, as modified by the simulator optics. The uniformity is $\pm 4\%$ as measured by a 4-cm^2 detector. Maximum beam divergence is 1 deg from the vertical. A water-cooled douser is provided to simulate solar eclipse of the beam.

A vibration exciter with a capability of 30,000 lbf is available for installation on an isolated seismic mount in the floor of the simulator.

Six hard-load points, each rated for 10,000 lb of vertical loading, are installed at each of three levels in the simulator for test-item support. These are oriented for 3- or 4-cable symmetrical support (90- or 120-deg spacing of hard-load points). A circumferential ring support can be installed at any of the three levels for cable orientation.

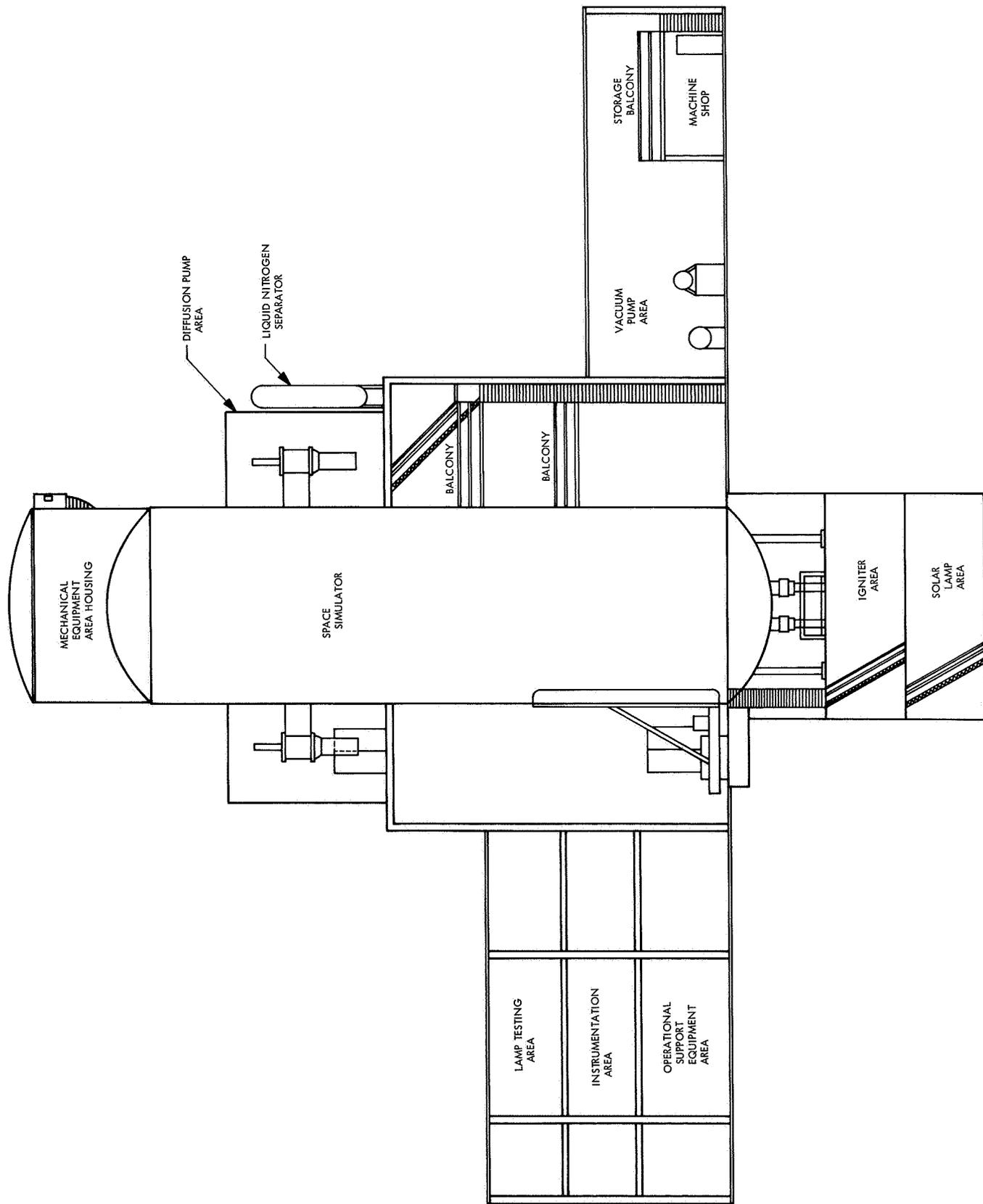


Fig. 1. JPL 25-ft space simulator facility

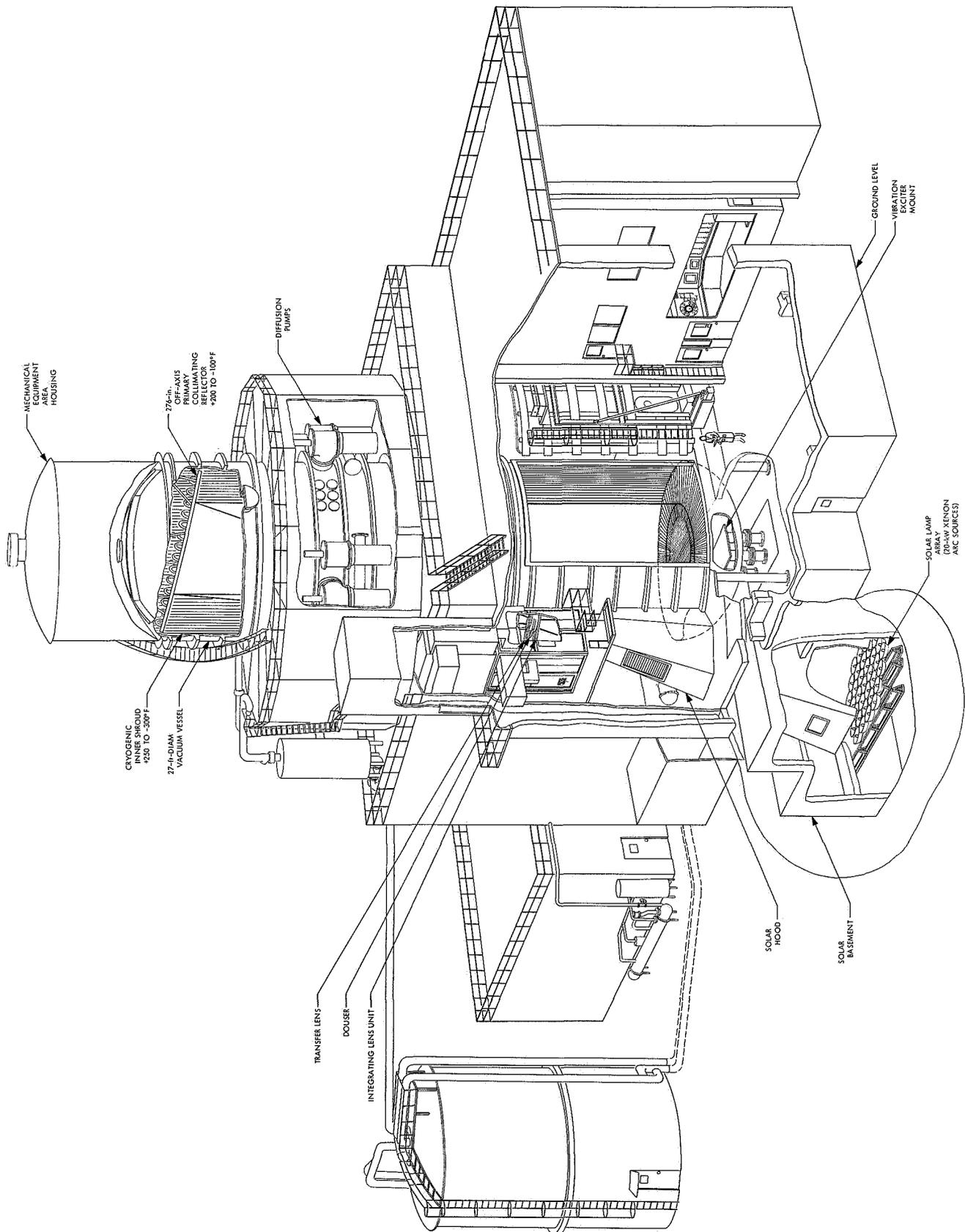


Fig. 2. JPL 25-ft space simulator

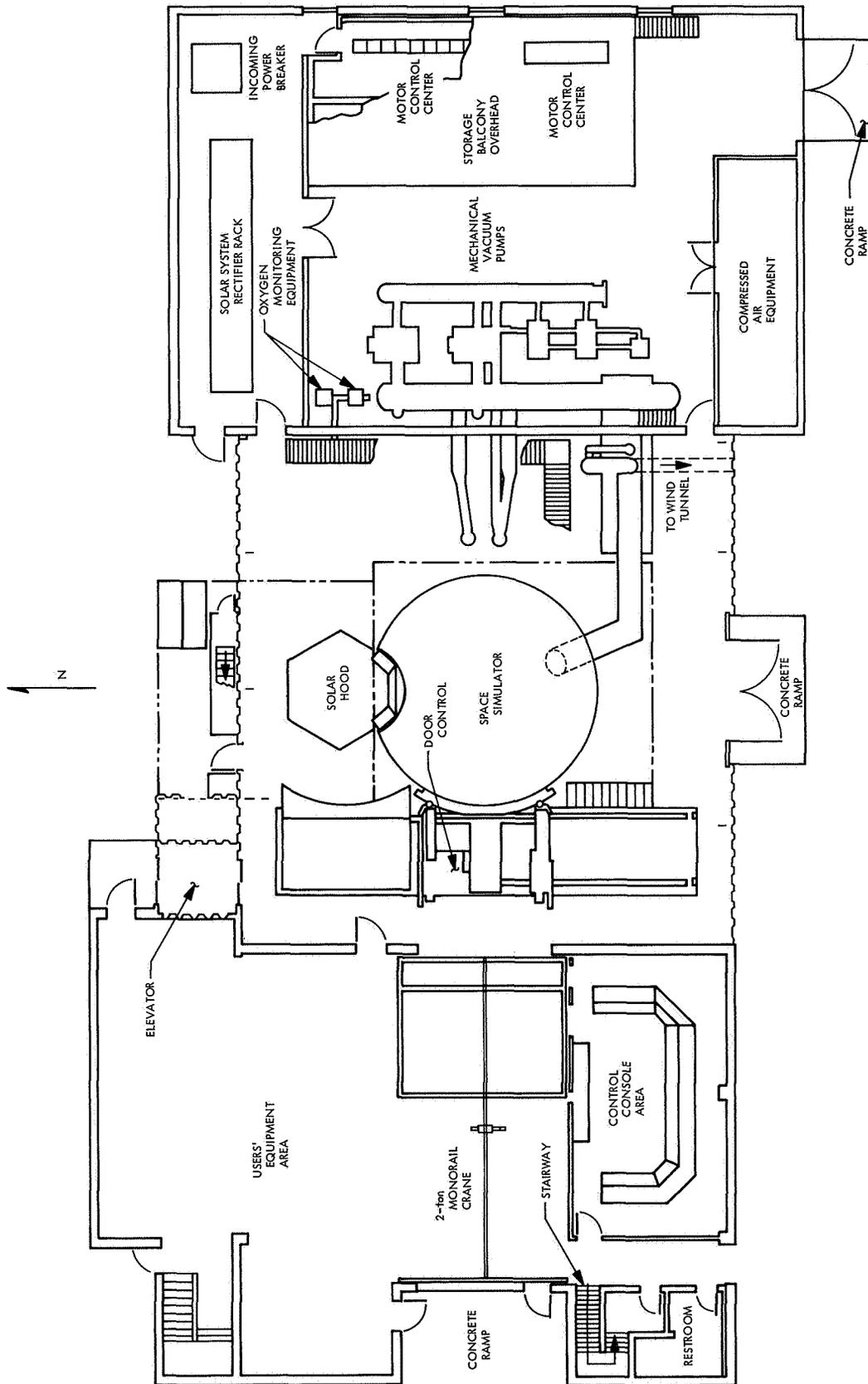


Fig. 3. Site plan, 25-ft space simulator

The space simulator is housed within a pressurized, air-conditioned building with separate areas for mechanical equipment, spacecraft preparation, test-monitoring equipment, and operational control. Operational monitoring and control are accomplished from a strategically situated graphic control console. Figure 3, a plan view of the facility, shows the major support items and areas. Table 1 lists the functional areas and their locations, and itemizes the maximum live loads for each.

A. Vacuum System

The volume of the vacuum chamber is approximately 52,000 ft³. The west wall of the chamber contains the hydraulically operated side-access door. A tier of 10 diffusion-pump ports, 42 in. in diameter, rings the chamber at a height of 54 ft (to centerline) from the floor level. These ports open to large right-angle gate valves attached to cryogenic baffles and diffusion pumps. A middle and bottom tier of similar pump ports (blanked at present) are placed 29 ft, 5 in. and 10 ft, 5 in. above the floor. The bottom head of the chamber contains a 36-in.-diam port, which is the entrance to the vacuum roughing line.

The vacuum system equipment consists of ten 50,000-l/s diffusion pumps (Consolidated Vacuum Corp.), two Stokes model 1713 blowers (rated at 6370 ft³/min), two Stokes model 1711 mechanical pump-blower combinations (rated at 300 and 1250 ft³/min), and one

Stokes model 412-H mechanical holding pump (rated at 300 ft³/min).

A 20-in. pipeline connects the simulator to the JPL wind-tunnel compressor plant for "roughing down" the chamber. This plant is capable of an evacuation rate of 82,000 ft³/min at atmospheric pressure and 1075 ft³/min at 2 torr. It can evacuate the chamber from atmospheric pressure to 6 torr in 10 min, thereby offering useful launch-profile test capabilities as well as providing an extremely fast roughing system for normal testing. Figure 4 shows a pressure profile for fast pumpdown. Table 2 lists the pumpdown sequence.

Table 2. Pumpdown sequence

Operational phase	Operational elements	Ultimate pressure, torr	Time required, min
1	Wind-tunnel compressors	6	10
2	Mechanical pumping system	5×10^{-2}	45
3	Diffusion pumps	5×10^{-6}	70

Table 1. Allowable live loads

Functional area	Live load (max), lb/ft ²
Optics laboratory (room 301)	75
Instrumentation area (room 201)	75
Operational support area (room 102)	1500
Spacecraft handling area (high bay, room 104)	1500
Rooms 202, 203, and 204 (south)	50
Rooms 303, 304, and 305 (north)	50
Rooms 308, 309, and 310 (south)	50
Console area (room 100)	1500
Mechanical pump room	1500
Storage balcony (mechanical pump room)	100
Roof area	20
Diffusion pump room	20
Diffusion-pump roof	30
Simulator balconies (each)	100
Chamber floor (no safety factor)	100
Chamber service platform	2000 lb/cable

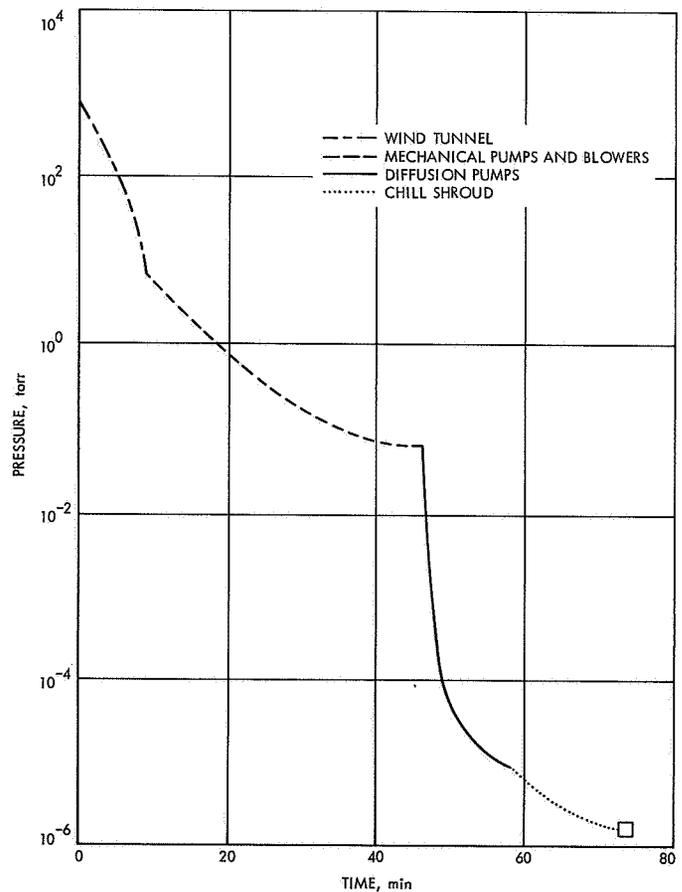


Fig. 4. Pumpdown curve

Chamber backfill to atmospheric pressure may be accomplished through the 20-in. wind-tunnel line. Air is passed through air dryers, and can be delivered at a maximum rate of 10,000 ft³/min with a dewpoint of -30°F. A secondary backfill procedure is available using dry nitrogen from an unlimited 100-psig source. Backfill to atmospheric pressure, using gaseous nitrogen (GN₂), can be accomplished in 30 min.

High-vacuum valves are installed at the inlets of all diffusion pumps, and each pump is equipped with a liquid nitrogen (LN₂) baffle to reduce oil backstreaming. All exterior vacuum-system piping is made of mild steel. Figure 5 is a schematic diagram of the vacuum system.

B. Cryogenic System

The cryogenic system (Fig. 6) operates either with LN₂ to approximately -320°F or with GN₂ in the temperature range of -250 to +250°F. All shrouds and associated piping inside the chamber are made from extruded aluminum. Other portions of the system—including the

blowers, pumps, heaters, and exterior piping—are made of stainless steel. All surfaces of the shrouds facing a test vehicle are coated with Cat-a-lac¹ flat black paint (463-1-8) for high absorptivity. The shroud surface facing the chamber wall and the inside surface of the chamber wall have highly reflecting surfaces to minimize radiant heat transfer.

The major components of the cryogenic system have individual thermal-control capabilities. These components are as follows:

- (1) A wall shroud that consists of five sections, including the door shroud and a "washer" shroud section at the diffusion-pump ports. Gaseous nitrogen may be used with a combination LN₂ chiller, 600-kW heater, and blower unit rated at 165,000 lb/h at 90 psig and 100°F (37,200 ft³/min). The temperature range is -320 to +250°F.

¹Trade name of a two-element polymerizing epoxy paint made by Finch Paint and Chemical Co., Torrance, Calif.

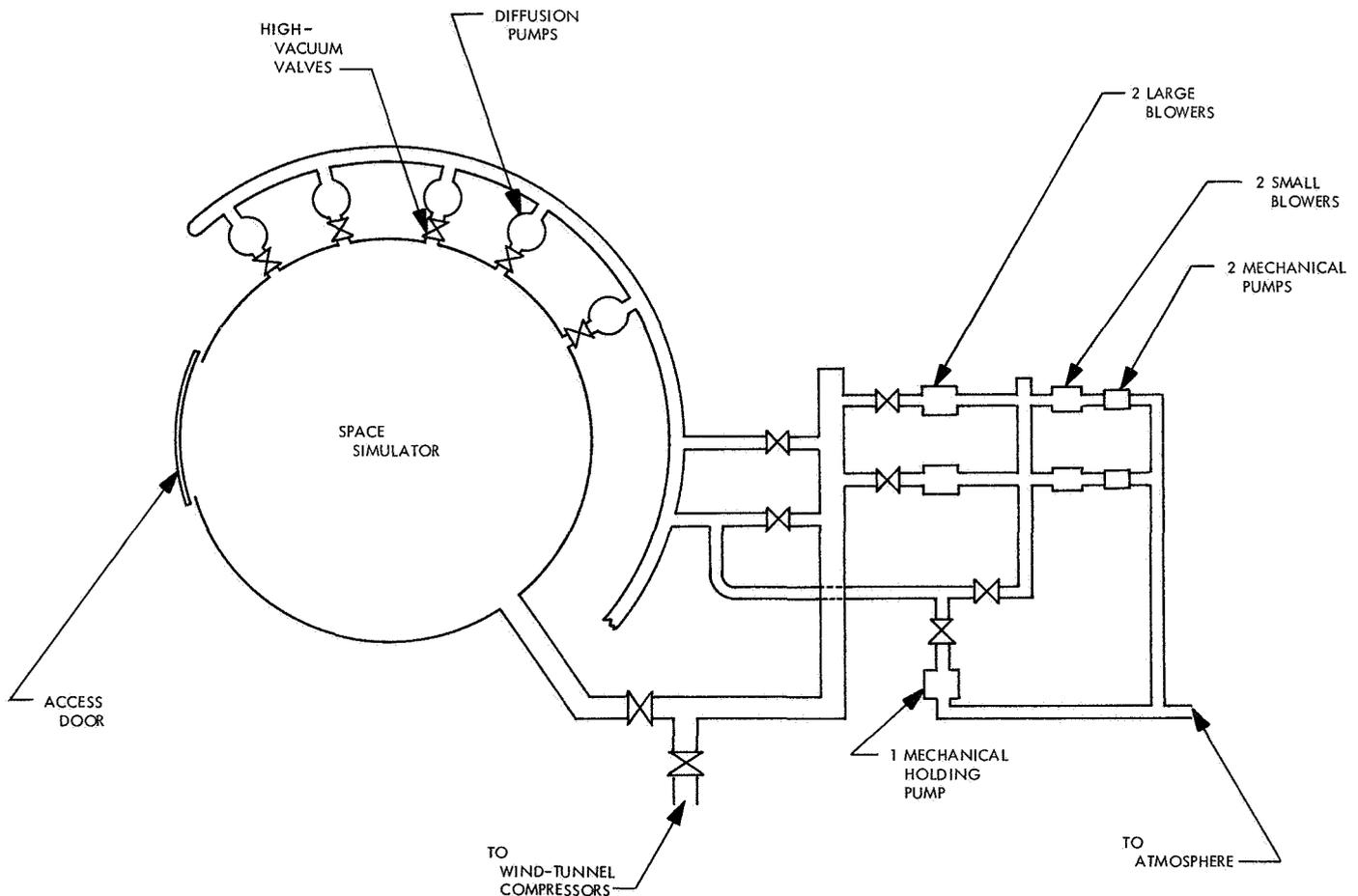


Fig. 5. Vacuum system schematic diagram (simplified)

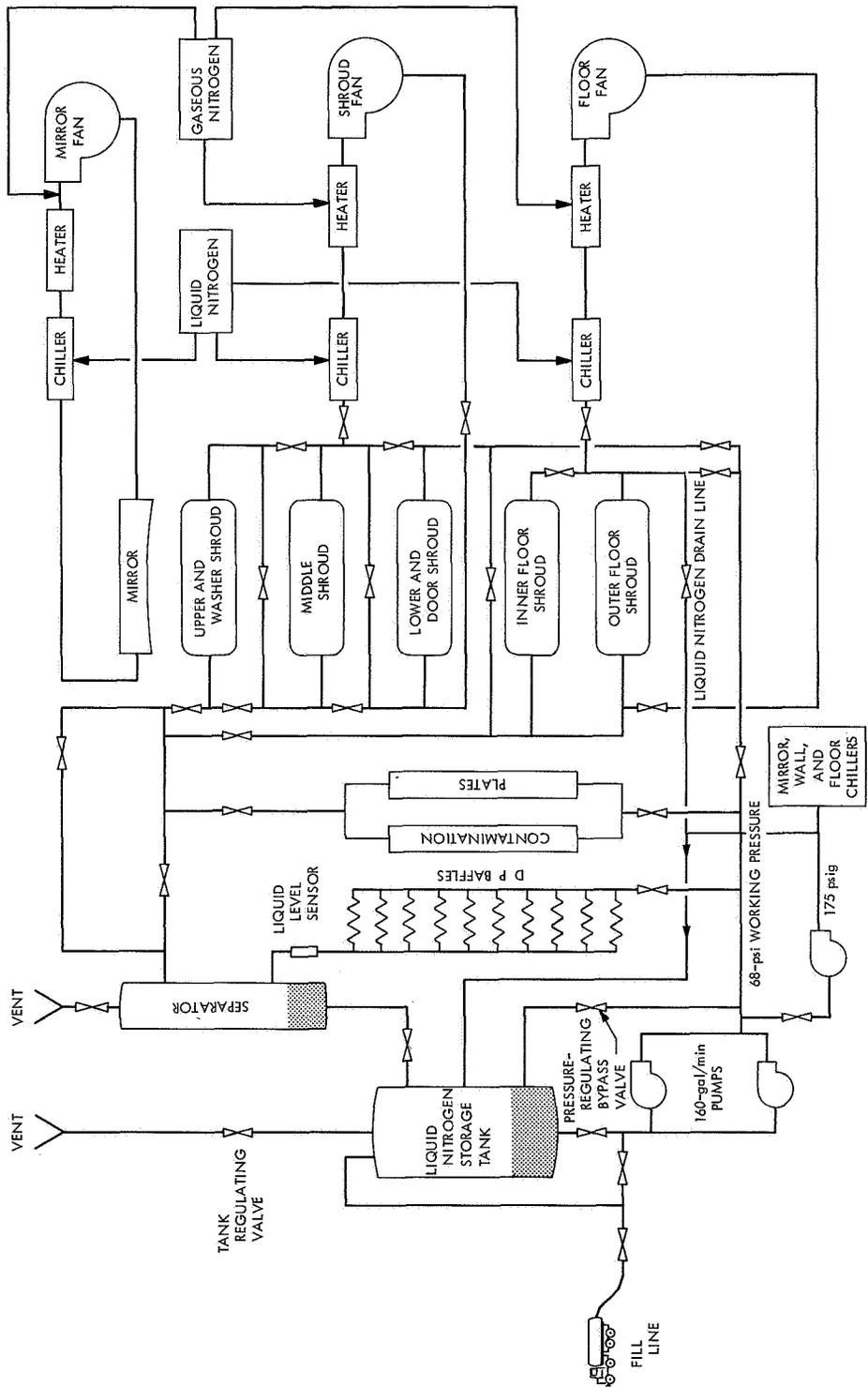


Fig. 6. Cryogenic system schematic diagram (simplified)

- (2) A floor shroud, which consists of an inner and outer section. Gaseous nitrogen may be used with an LN₂ chiller, heater (75 kW), and blower rated at 21,300 lb/h at 90 psig and 100°F (8300 ft³/min). The temperature range is -320 to +250°F. The 12-ft-diam inner section is capable of maintaining a temperature of -275°F with a heat load of 900 W/ft² (intensity at the planet Mercury). The outer section, which extends to a diameter of 20 ft, is capable of maintaining a temperature of -275°F with a heat load of 275 W/ft² (equivalent to the intensity at the planet Venus).
 - (3) Collimating mirror-cooling equipment (GN₂ only), which consists of an array of cooling passages welded to the back of the mirror with a combination chiller, 300-kW heater, and blower rated at 32,000 lb/h at 90 psig and 200°F (7200 ft³/min). The temperature range is -100 to +200°F.
 - (4) Two contamination plates, each of which consists of a stainless-steel, plate-coil panel approximately 12 ft² in area. These plates, cooled with LN₂ early in the pumpdown cycle, serve as cryogenic traps for the free condensable gases in the chamber. They are maintained at LN₂ temperature throughout the test period and chamber warmup to prevent gaseous contamination of the test item. A 2.5-kW heater is available for warmup.
 - (5) Diffusion-pump baffles—10 nickel-plated copper, chevron-type baffles that are integrally mounted in the top of each diffusion pump.
- (1) Lamp array—a 37-lamp array (Fig. 7) that comprises a hexagonal grouping of 20-kW compact xenon arc lamps mounted in 26.75-in., water-cooled, ellipsoidal reflectors with an F₁ of 4 in. and an F₂ of 544 in. The Kanigen-coated, cast-aluminum reflectors have a capture angle of 116 deg. Each lamp operates with a dc input of 45 V at 450 A. Capacitor discharge, spark-gap igniters, included in each lamp circuit, furnish a 50-kV pulse to establish the arc.
 - (2) Mixing lenses—these consist of an entrance- and an exit-lens assembly, each approximately 20 in. in diameter and made up of 19 hexagonal lenses. The entrance (condensing) lenses are mounted in a water-cooled copper frame; the exit (transfer) lenses are mounted in an air-cooled stainless-steel frame. The mixing-lens spacing is adjustable to optimize focusing and permit minor adjustments of the beam size. All lenses are plano-convex and are made from fused silica. The mixing lenses are mounted outside the chamber in front of a 27-in.-diam lens with a 750-in. focal length. This lens is the solar window into the tank and acts as a vacuum seal.
 - (3) Collimator—this is a 276-in.-diam aluminum weldment with a thickness of 2 in. It is structurally reinforced with a number of 14-in. ribs. The front surface is machined and polished to a spherical radius of 1200 in. A 20-mil coating of electro-deposited nickel is the substrate for the aluminized surface, which is 700–1000 Å thick. The mirror is hung from the top head of the tank by a whiffletree suspension system that connects to the chamber head at three points. The mirror perimeter has 12 equally spaced attachments to the whiffletree. Internal cooling with GN₂ is provided.
 - (4) Power source—dc power supplied through a total of 111 rectifiers, each rated at 200 A. The rectifiers, connected in parallel groups of three, furnish power to the lamps through a water-carrying channel of 4 × 4 × 0.5-in. copper.
 - (5) Scaffold hoist—a ring scaffold suspended from four cables, which can raise and lower a platform inside the chamber for equipment maintenance. The surface of the mirror can be reached from this platform for maintenance and aluminizing.
 - (6) Solar hood—a sheet-metal enclosure for the solar beam. It is located between the solar basement, where the lamp array is located, and the solar

During liquid-phase operations (except at cooldown), the LN₂ system operates as a fully flooded, single-phase system. Cooldown time from ambient to LN₂ temperature is about 1 h.

All LN₂ is supplied to this chamber from a 28,000-gal LN₂ storage tank used in common with the JPL 10-ft space simulator. The GN₂ is obtained from a 2000-psi JPL distribution system. Shroud temperatures are monitored at multiple points on the wall and floor shrouds.

C. Solar Simulator System

The installed system (see Fig. 2) is capable of producing an illuminated, slightly barrel-shaped cylindrical test volume with a diameter of 15 ft. Its useful height is 25 ft, which is established by uniformity considerations and direct infrared radiation from the solar-penetration window that is 25 ft above the floor. The major components of the solar simulator system are as follows:

window in the vacuum vessel. Cooling is provided by a filtered recirculating air system containing a heat exchanger for temperature control and activated charcoal filters for ozone removal.

Light from the hexagonal grouping of arc lamps, modified by the mixing lens, passes through the window lens into the vacuum vessel. The light impinges on the one-piece collimating mirror and is reflected as a collimated "off-axis" beam of light into the test area.

Because of the design of the off-axis optical system in the simulator, some consideration must be given to the presence of re-reflected solar energy within portions of the test volume. Light from a highly reflective plane surface which is "looking up" into the collimating mirror, and which is not properly oriented within the solar beam, can be reflected back into the test volume, producing a local increase in beam intensity. An understanding of this phenomenon makes it possible, however, to eliminate or significantly reduce this undesirable effect to an acceptable level.

The solar simulator is currently capable of providing a stable light-intensity level at any point between 0 and 314 W/ft². The intensity level can be controlled by varying the number of lamps in use and by adjustment of the voltage supplied to each lamp. Radiometers in the test

volume of the chamber measure the intensity of the radiation. Table 3 describes the existing and projected solar-simulation performance.

III. Supporting Systems

A. Electrical Power

The power supply is a 2500-kVA, 3-phase supply transformed from 2400 V (3-phase delta) to a 480-/227-V, 3-phase "Y" configuration. From switching gear located in the rectifier room, this power is distributed to four rectifier power panels (PRA, PRB, PRC, and PRD), three motor-control centers (PB, PC, and PD), the shroud heater-control panel (PM), and the wall shroud blower. The motor-control centers, in turn, provide power to a secondary distribution system of eight panels for lighting, controls, and low-power applications.

Motor-control center PD furnishes power to a cross section of equipment, controls, and lighting circuits that are selected to allow normal operation or shutdown of the facility. If there is a power failure, an automatic transfer switch connects this control center to an emergency generator, and operations can continue by manual resetting of the equipment. Restart of lighting in control room and equipment areas is automatic.



Fig. 7. Compact arc lamp array

Table 3. Current and projected solar-simulation performance

Diameter of beam, ft	Number of lamps	Intensity, W/ft ²						Collimation half-angle, deg	Uniformity, %
		20-kW lamps		24-kW lamps ^a		30-kW lamps			
		Sustained	Max	Sustained	Max	Sustained	Max		
15	37	236 ^b	314 ^b	283 ^b	376 ^b	354 ^c	470 ^c	1	± 5
8 ^d	7	174 ^e	220 ^e	210 ^e	264 ^e	260 ^c	330 ^c	1	± 5
20 ^f	37	133	177	160	212	260	330	1	± 5
20 (proposed) ^g	61	224	300	269	357	336	447	1	± 5
8 (Mercury) (proposed) ^h	37	970	1260	1160	1510	1450	1890	2	± 5
5 (25 solar constant) (proposed) ⁱ	37	—	—	—	—	3250	4060	3	± 5
6.5 (25 solar constant) (proposed) ^j	61	—	—	—	—	3250	4060	3	± 5

^aPresent lamp power supplies are limited to 24 kW max.
^bAvailable at present.
^cProposed.
^dRequires a new integrating lens unit (on order).
^eOn order.
^fRequires a new integrating lens unit.
^gRequires addition of 24 lamp assemblies, power supplies, and a new integrating lens unit.
^hRequires installation of a 10-ft-area collimator and a new integrating lens unit.
ⁱRequires a new small collimator and a new integrating lens unit.
^jRequires a new small collimator, 24 additional lamp assemblies, power supplies, and a new integrating lens unit.

An isolated electrical ground is provided for instrumentation use by the spacecraft test complex. Accessible ground-plate connections are available in rooms 100 and 200. The 10-ft copperweld ground rod passes through a caisson containing magnesium sulphate for minimum ground resistance.

B. Emergency Power

A 400-kW, 3-phase, 480-V, diesel-powered generator is automatically connected to motor-control center PD, from which facility operations can be continued if there is a power failure. A 2½-day fuel supply is stored underground. A 75-kW, 3-phase, 480-V generator powered by natural gas provides standby power, which is transformed to 3-phase 120/208 V and supplied to the spacecraft command and monitoring-equipment circuit outlets in the system test complex.

C. Cooling Water

Treated, filtered water is furnished in a closed-loop system having 8-in. supply and return lines. Three 75-hp pumps (one of which is on standby) provide 680 gal/min at 150 psig each. Water from an updraft cooling tower is used as a heat-exchange medium in the two cooling coils of this system. The rated capacity of the system is given in Table 4.

Water, used for cooling, is available from local municipal sources if there should be an emergency. Cooling water is piped to various areas, listed in Table 5, where a regulated supply is manifolded to individual equipment.

Table 4. Capacity of cooling-water system

Parameter	Value
Cooling coil capacity	1600 gal/min
Outlet temperature	95°F
Inlet temperature	107.7°F
Cooling capacity	1800 kW
Wet-bulb temperature (max)	72°F

Table 5. Equipment receiving cooling water

Equipment	Inlet pressure, psig
Vacuum pumps and blowers	24
Air-conditioning system	50
Solar lamp reflectors	50
Solar lamps and copper bus heat exchanger	50
Mixer lens holder and light douser	100
Solar hood cooling coil	50
Diffusion pumps	50

D. Pneumatic System

Air is obtained from a 115-psi distribution system that is used throughout JPL. If this supply pressure drops below 100 psig, a 40-hp, 200-ft³/min compressor starts automatically to supply air to the facility. This air supply is used for valve controls, air hoists, overhead-crane pin actuators, utility outlets, and—by means of appropriate filters—for emergency breathing apparatus.

Gaseous nitrogen is obtained from a 2000-psig, Laboratory-wide distribution system that is reduced to 100 psi for distribution within the facility. The GN₂ is used (1) to drain the shrouds and baffles of LN₂, (2) as the "fluid" for operating the shrouds between -250 and +250°F, (3) for temperature control of the mirror, (4) for chamber backfill, (5) for mechanical-pump gas ballast, and (6) for pressurizing insulation of the LN₂ storage tank.

E. Hydraulic System

A hydraulic system, mounted on the carriage that operates the 15- × 25-ft side-opening simulator access door, consists of a 12-gal/min (at 1000 psi) pump, a 60-gal tank, and a 5-gal accumulator with piping to the following actuators: (1) carriage traverse motors, (2) main door retracting cylinders, (3) drawbridge lifting cylinders, and (4) personnel door latch cylinders.

A stationary hydraulic unit is installed in the vacuum vessel basement for actuating the main door wedge locks and seal clamps. The unit consists of a 19-gal/min (at 500 psi) pump, a 60-gal tank, and a 5-gal accumulator.

F. Air Conditioning and Ventilation

The 25-ft space simulator facility is divided into three separate zones of air control. The west end of the building, which contains three floors of offices, shops, the control room, and the system test complex area, is completely air conditioned. Cooling is supplied from two 29-ton refrigeration units; heating is supplied by a 900,000-Btu gas-fired boiler.

The center section of this building, which contains the simulator chamber, is ventilated by four roof-mounted fans rated at 10,000 ft³/min. Air is discharged through shuttered wall louvers at the floorline. A ¾-hp exhaust blower is installed in the simulator basement, with inlet openings at the basement floor level and an outside discharge for dissipating nitrogen gas that may accumulate in the basement from leaks or spilled LN₂. A ½-hp exhaust blower is similarly installed in the solar simulator basement. Two 3300-ft³/min heater-fan units supply heat for the simulator room.

The east mechanical-equipment room has three ½-hp roof-mounted exhaust fans for ventilation and five gas-fired radiant space heaters. A 30-hp fan is mounted on the roof above the power-supply racks in the rectifier room to cool the units and to ventilate the room.

IV. Test-Item Installation

The spacecraft or test item is generally hung by cables or hard-mounted from the chamber floor structure (Figs. 8 and 9). Support-induced vibration has been measured and analyzed using a cable suspension system for spacecraft support.²

A test setup area is provided in the central portion of the control room opposite the large entrance door. It may be used as operating space for handling and checkout of test articles. This area is serviced by a 3-ton bridge crane covering a span of 15 × 26 ft, with a hook height of 25.5 ft. The hoist has vertical-lift speeds of 4 and 12 ft/min and horizontal speeds of 18 and 40 ft/min. A 2-ton monorail traveling-beam crane is available for test-item transport from the setup area to the support system inside the chamber. This monorail crane has a hook height of 21 ft, 7 in. The monorail travels at a speed of 20 ft/min. The trolley travels on the monorail at speeds of 5 and 15 ft/min. The vertical travel of the hoist is 5 and 15 ft/min and includes a microdrive control that limits speeds to 1 ft/min.

V. Facility Instrumentation Systems

A. Pressure

For the pressure range from 1.0 atm to 10⁻³ torr, pressure profiles are measured and recorded by two differential-vacuum, bridge-type measuring systems. Each system consists of two measuring heads. One head indicates the range of 0 to 10³ torr; the other ranges to 10 torr full-scale. With the 10-torr head, it is possible to measure pressures down to 10⁻³ torr.

Ionization-gage systems are used for pressure measurements below 10⁻³ torr. The ionization gages can be mounted in various positions inside the chamber to accommodate test requirements. Redundant gages are used as safeguards against data loss in case of gage or controller failure.

²The findings of this analysis are described in detail in *Vibration Survey of the 25-ft Space Simulator*, a JPL internal report dated April 1, 1969.

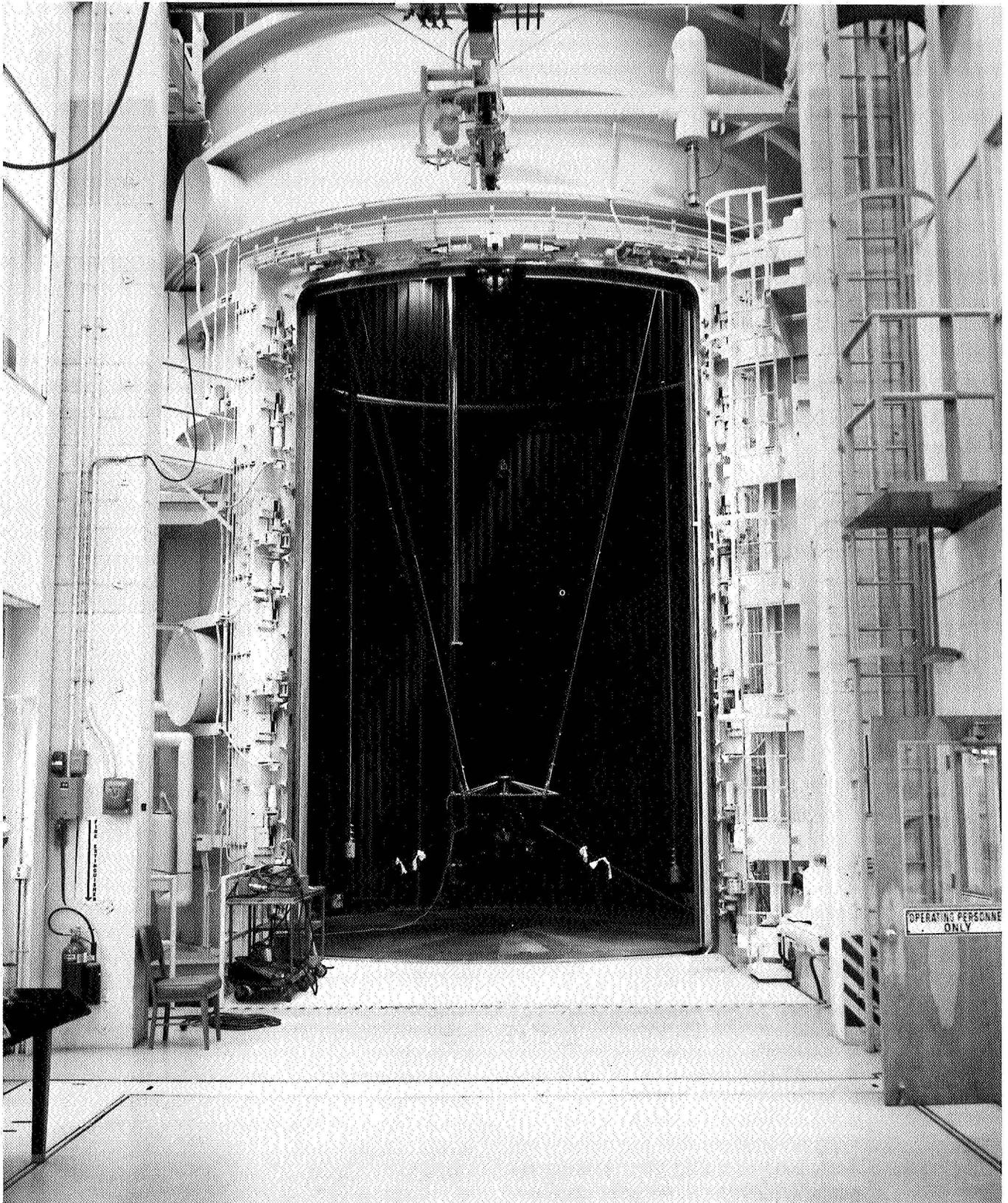


Fig. 8. Typical cable-mounted suspension system

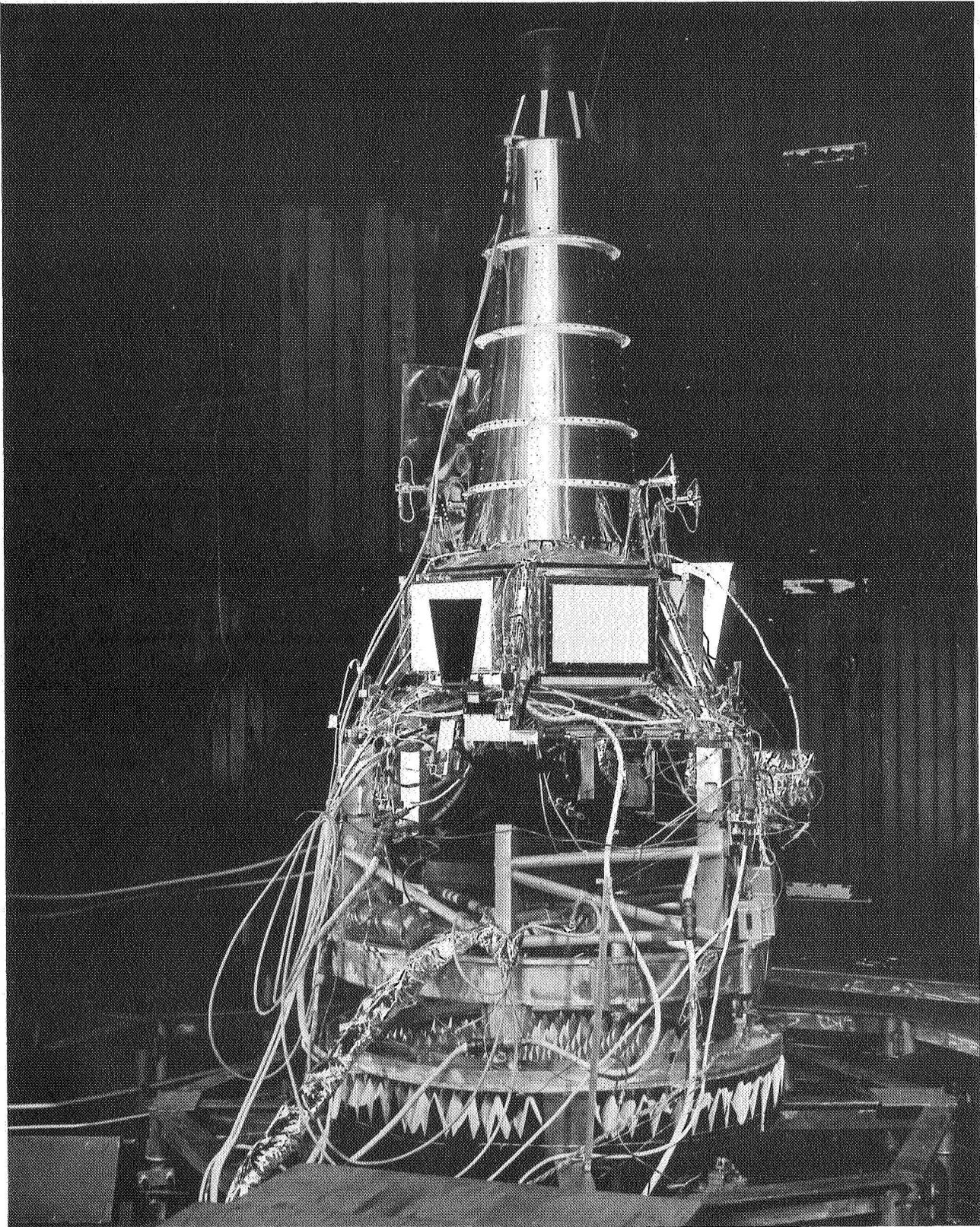


Fig. 9. Ranger spacecraft floor-mounted in the 25-ft space simulator

B. Temperature

For temperature measurements, sufficient thermocouple transducers are available to accommodate 400 data channels. The transducers are Chromel Constantan types, with a temperature range of -320 to $+1800^{\circ}\text{F}$. In addition to the thermocouple devices, 12 excitation channels are available for resistance-type temperature sensing.

C. Solar Radiation

Two types of radiometer, HyCal³ and the JPL absolute cavity radiometer, or ACRAD, are used to measure solar intensity during each test. The ACRAD, with an overall error of less than 1% of full scale, is considered a primary reference. Figures 10 and 11 show both radiometer types.

1. HyCal radiometer. The HyCal (model 8400) radiometers are water-cooled and may be used with or without quartz windows. These devices employ a patented process, the "Hy-Therm" principle, which is a method of conductively transferring heat so that the response remains constant whether the measurements are made in a vacuum or in an atmosphere. To accomplish this "conductive dominance," the radiometer contains two banks of thermojunctions separated by an insulating wafer. The wafer is irradiated on one side and attached to a heat sink on the other. The output of the HyCal radiometer is linear to several solar constants; its sensitivity is 0.043 mV/W/ft^2 . The response time ($1/\epsilon$) is 0.25 s.

2. Absolute cavity radiometer. The JPL Instrumentation Section, in conjunction with the Applied Mechanics Section, developed the absolute cavity radiometer described in Refs. 1 and 2. This device employs a platinum wirewound cone inside a guard heater. The platinum wire acts as a highly sensitive resistance thermometer as well as a heating element. The guard is maintained at a preset constant temperature that is determined by the irradiance range desired. The cone temperature is slaved to the guard temperature by using the platinum heater element.

In the vacuum environment of cold, black space, the electrical power into the cone is radiated out from the cone following the formula $A\sigma T_r^4$, where A is the cone aperture area, σ is the Stefan-Boltzmann constant, and T_r is the cone temperature. No heat transfer between the cone and guard occurs because they are both at the same temperature. If the cone is now irradiated, less electrical power will be needed to maintain its temperature. This

³Manufactured by HyCal Engineering, Santa Fe Springs, Calif.

electrical power difference is a measure of the irradiance; it is useful only for measurements under vacuum conditions. The effective time constant is on the order of 10 s. The accuracy is reported to be better than 1%.

D. Vibration

A vibration system of 30,000 lbf can be installed at floor level inside the space simulator. All vibrations generated by the vibration system are isolated from the space-simulator structure.

E. Spacecraft Power Cutoff System

The power cutoff system consists of three ionization gages and a control unit. Its purpose is to turn off spacecraft power if there is an uncontrolled increase in chamber pressure. To actuate the shutdown circuit, all three ion gages must sense the pressure increase.

A solar-simulation alarm system is also provided. This system senses solar output and triggers an alarm when adjustable high or low test limits are exceeded.

VI. Test-Item Instrumentation System

The instrumentation recording area is located on the second floor north of the high bay. This area contains much of the data-conditioning, data-presentation, and temperature-control equipment. The raw data signals from the test item are transferred via wire pairs through the bottom of the space simulator to the recording area. These signals are conditioned, reduced to engineering units, and displayed for use. Also located on the second floor is a work area for technicians and for cognizant temperature-control personnel.

A. Data Acquisition

The temperature-measuring system is designed to accept 400 channels of data from either Chromel Constantan or copper Constantan thermocouples. The thermocouple input connectors each accommodate 25 circuits. This system can be altered to accept other input configurations when necessary.

Vibration data acquisition gear is not normally installed in the space simulator, although it is available and can be supplied as necessary.

Representative channels of temperature, pressure, and solar-radiation levels can be selected from the environmental control console and recorded as part of the test record.

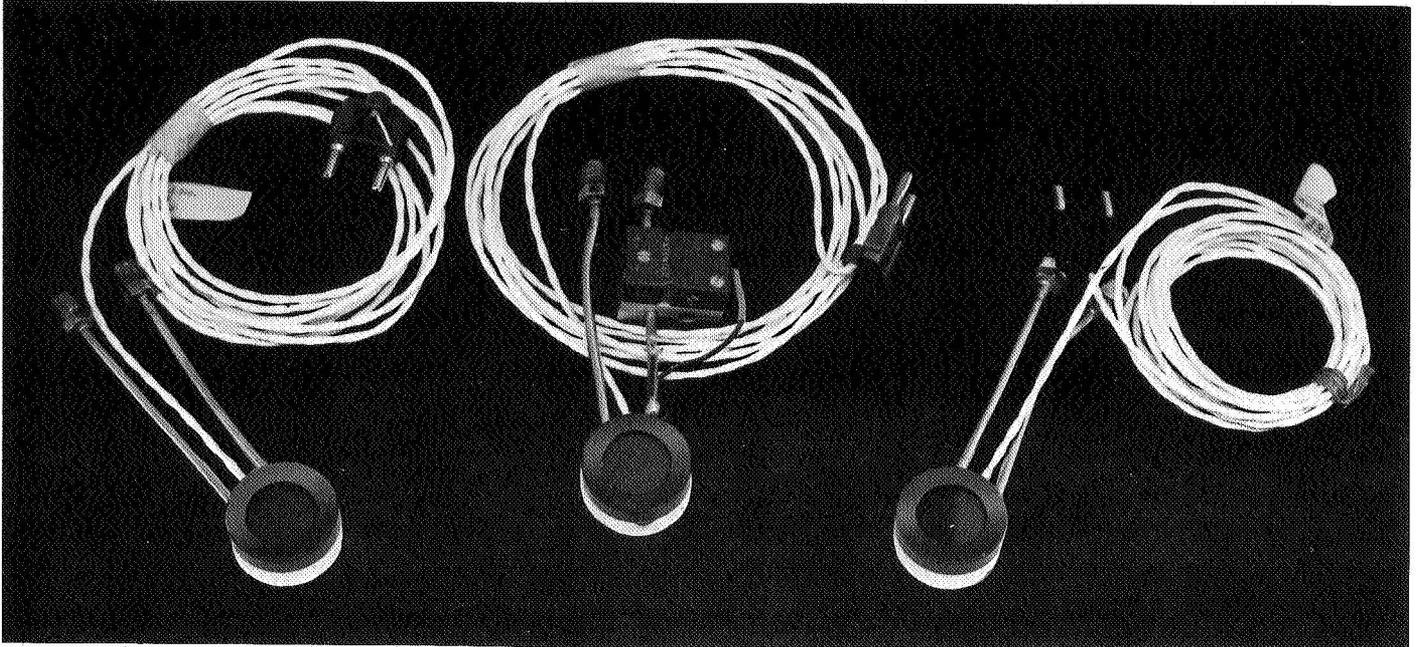


Fig. 10. HyCal solar monitoring radiometer

Input lines for 50 signals are available inside the space simulator. Provisions have also been incorporated for obtaining pressure data from 12 strain-gage transducers.

B. Data Conditioning

1. *Thermocouple referencing.* The reference is an electronically controlled, 150°F isothermal oven located in the pit beneath the space simulator. A measurement is taken of a known temperature for accuracy verification.

2. *Multiplexing.* The multiplexer and its controls are located in the recording area. Although there are 512 channels at present, this number can be increased to 1000. Of the input data channels, 112 go directly from the space simulator to the multiplexer, and 400 go to the patch panel for local display or distribution. The multiplexer has a maximum scanning rate of 50 channels per second and can be remotely controlled by computer. When a scan is initiated during normal operation, the multiplexer will scan all channels and stop. During setup, it is possible to address each channel individually. The output of each channel from the multiplexer is amplified and converted to a frequency proportional to the input analog level. This signal is available for data reduction.

In the recording area, dc amplifiers, filters, and galvanometer attenuation panels are available for use as necessary.

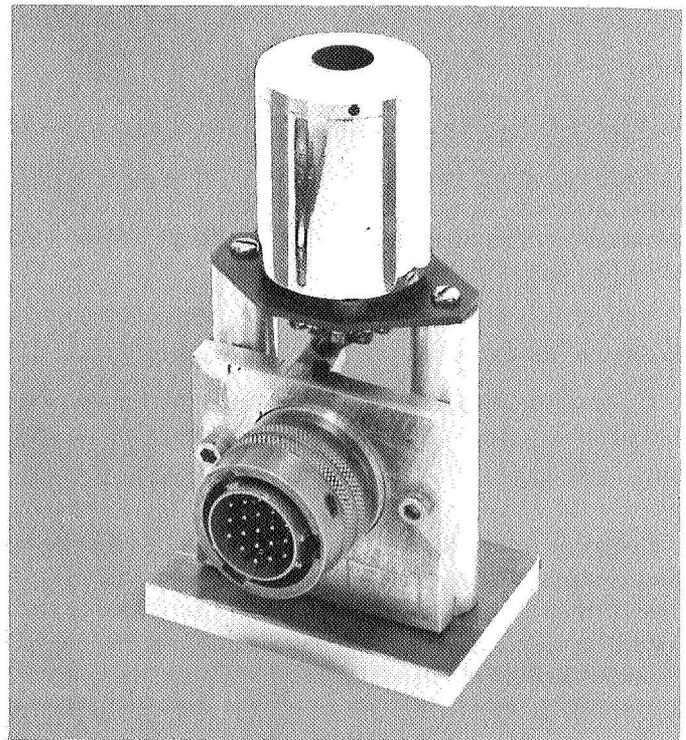


Fig. 11. ACRAD solar monitoring radiometer

C. Data Reduction

The signal output of the multiplexer is transmitted by cabling to the JPL data analysis facility, where a PDP-4 computer with magnetic tapes is available for receiving

the signal and converting it to engineering units. The reduced data are stored on digital magnetic tapes for future access and are also transmitted back to the recording area for real-time presentation.

D. Data Presentation

1. *Digital printout.* A Teletype printer is located in the recording area to record the results of the reduced scan. Also, selected environmental parameters can be transmitted to the central recorder in the operation support equipment area. These signals are conditioned and isolated before transmission.

2. *Digital magnetic tapes.* These tape units are located in the data analysis facility. The data stored on these tapes can be programmed through the IBM 7094 computer for further data reduction or plotting.

3. *Analog recording.* Both Leeds and Northrup⁴ and Moseley⁵ single- and double-pen oscillographs are used in the recording area. In addition, one 50-channel Midwestern direct-write oscillograph is available as needed.

4. *Analog magnetic tapes.* Normally, there are no analog tape recorders in the instrumentation recording area; however, there are 50 interconnecting channels to the recording room in an adjacent building, where tape recorders are available on short notice.

E. Temperature Control

1. *Heater controllers.* The space-simulation system has 100 variable-voltage transformers, each capable of an output of 300 W.

2. *Power transducers.* The system has 50 power transducers, each rated at 60 W max, for direct readout of test-item heater power. These transducers have a millivolt output proportional to the power input, which can be recorded as part of the test data.

3. *DC voltage supplies.* A number of dc voltage supplies are available, together with precision shunts and meters for making accurate low-power measurements.

⁴Manufactured by Leeds and Northrup Co., North Wales, Pa.

⁵Manufactured by Moseley Division of Hewlett-Packard Co., Pasadena, Calif.

VII. Facility Design Characteristics

Facility design features that have been incorporated into the construction of the systems that make up the 25-ft space simulator are described below.

A. Vacuum System

The working fluid is assumed to be air at 70°F. The stainless-steel vessel, 27 ft in diameter and 85 ft high (with spherical heads), has a volume of approximately 52,000 ft³ and a surface area of approximately 9400 ft².

Design techniques were established for an ultimate pressure of 5×10^{-7} torr; the actual vacuum capability is 10^{-6} torr. The 10^{-6} pressure can be attained within 70 min with the chamber empty, cold walls filled with liquid nitrogen, and diffusion pumps operating. (Figure 4 shows a typical pumpdown curve for the chamber.) All valves, pressure controllers, regulators, motors, and other equipment normally required to operate the vacuum-pumping system are controlled from—and indicated on—the main console.

The high-vacuum plant is designed to maintain full operation with one Stokes model 1711 mechanical pump and blower functioning. A holding pump is installed to back the diffusion pumps while the main roughing system is pumping down the chamber. All valve operations are pneumatic, with operating air pressures of less than 80 psi.

No component or portion of the vacuum system is located outside the building enclosure. Vacuum piping operating at 10^{-3} torr and higher is fabricated from mild steel, as are the main distribution lines for house and control air and GN₂. Pneumatic equipment control connections are fabricated from copper tubing.

B. Cryogenic System

The shroud temperature range is from -320 to $+250$ °F. The working fluid is LN₂ at saturation temperature and pressure (about -320 °F). Gaseous nitrogen is used between -250 and $+250$ °F.

Cool-down time from ambient to LN₂ temperature is 1 h max. The LN₂ is drained from the shroud system in 30 min and returned to storage with a GN₂ blowback system. (With the shrouds filled with LN₂, the rate of change of temperature from -320 to $+100$ °F is sufficient to make the change in 1 h.)

The wall shrouds are made of weldable, extruded 3003 aluminum alloy, suitable for -320 to $+250^{\circ}\text{F}$ service, and of 1/8-in. min thickness. All pressure tubing has a minimum wall thickness of 5/32 in. All shroud surfaces facing the chamber wall are polished, and all surfaces seen from the test volume are painted black to have a solar absorptivity higher than 0.90 in the 0.2- to 3.0- μm band. The floor shroud is covered with a removable structural floor made from aluminum honeycomb panels designed for a live load of 100 lb/ft². A 12-ft-diam, separately removable center section is provided in the floor to accommodate an exciter installation for vibration tests. Supports for the floor are fabricated from 304 stainless steel. The heater and blower for the floor shroud serve as the emergency warmup unit for the entire cold-wall system.

The wall-shroud blower is so piped that the floor shroud can be operated at the same temperatures and pressures as the wall shrouds. The floor shrouds are operable in gas-phase temperatures, while the wall shrouds are in liquid phase.

Shroud ducts are so designed that the temperature increment between the inlet and outlet of any section does not exceed 50°F during warmup. Shroud temperatures between ambient and -250°F are obtained by LN₂ evaporation and circulation from within the circuit. Pressures are automatically controlled to any set point within the design limit by pressure-controlled modulating valves.

The design pressure is 100 psig; normal operating pressure is 75 psig. The shrouds are designed to provide a thermally opaque test volume above the chamber floor that is 20 ft in diameter and 25 ft high. The floor heat load is assumed as 275 W/ft² over a 20-ft-diam circle. No point on the shrouds is warmer than -275°F when operating with LN₂. The 12-ft-diam center section is capable of maintaining a temperature of -275°F with a heat load of 900 W/ft² (planet Mercury intensity). The temperature regulation is $\pm 5^{\circ}\text{F}$ from a set point between -175 and $+250^{\circ}\text{F}$, and $\pm 10^{\circ}\text{F}$ from a set point between -175 and -250°F . No steady-state operations are performed between -250°F and LN₂ temperature.

On the roof of the building, an LN₂ separator tank is installed at the high point of the system to maintain a head on the system during liquid-phase operations and to provide shroud venting and regulated GN₂ blowoff to the atmosphere. All external piping is insulated. All cryogenic penetrations in the vacuum vessel have isolation-type insulators.

Two circulating pumps, rated at 160 gal/min at 200-ft head pressure, supply LN₂ to the system. One LN₂ booster pump, rated at 100 gal/min, supplies the chiller circuits for intermediate temperature control. Each pump is provided with an automatically controlled, manually adjustable bypass valve to ensure operation under fixed conditions without loss of prime.

Relief valves are installed in each portion of piping or section of shroud that can be isolated by valves. All relief valves are vented outside the building. All valves required to operate the system have pneumatic actuators controlled and indicated at the console. Thermocouple readouts are provided on a multiple-point recorder.

All heaters operate at full power to within 20°F of the set point, at which time 80% of the power is cut out and the remaining 20% is regulated by a saturable-core reactor, which is controlled by a proportional controller. The maximum sheath temperature of the heaters is 1000°F .

Valve position and interlock devices are integrated with the unit served.

C. Solar Simulation System

The prime characteristics of the solar simulation system are as follows:

Parameter	Value
Test volume size	15 ft diam by 25 ft high
Intensity	270 W/ft ² max
Uniformity	$\pm 4\%$
Collimation	1 deg half-angle
Spectrum	xenon arc lamps

The collimating mirror cooling system is designed for a heat load of 20,000 lb of aluminum, with an estimated cooling requirement of 15 kW. Gaseous nitrogen is used as the working fluid, regulated to $\pm 10^{\circ}$ from -100 to $+200^{\circ}\text{F}$, with a rate of change of 200°F/h . The design pressure is 100 psig; operating pressure is 75 psig.

The solar basement, lamp-array structure, and power-source installation is designed to permit the addition of lamps to produce a 20-ft-diam earth constant. The solar hood is gas tight and designed for 1 in. of water internal pressure and a temperature range of 80 to 140°F .

VIII. Summary

The 25-ft space simulator at JPL is designed for environmental testing of unmanned spacecraft under simulated interplanetary conditions of extreme cold, high vacuum, and intense solar radiation. The present status of the facility, supporting systems, test-item installation,

procedures,⁶ instrumentation systems, and design characteristics are as described in the preceding sections. Allowances for future modifications, where applicable, have also been described.

⁶Procedures are described in *25-ft Space Simulator Standard Procedures*, a JPL internal document.

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